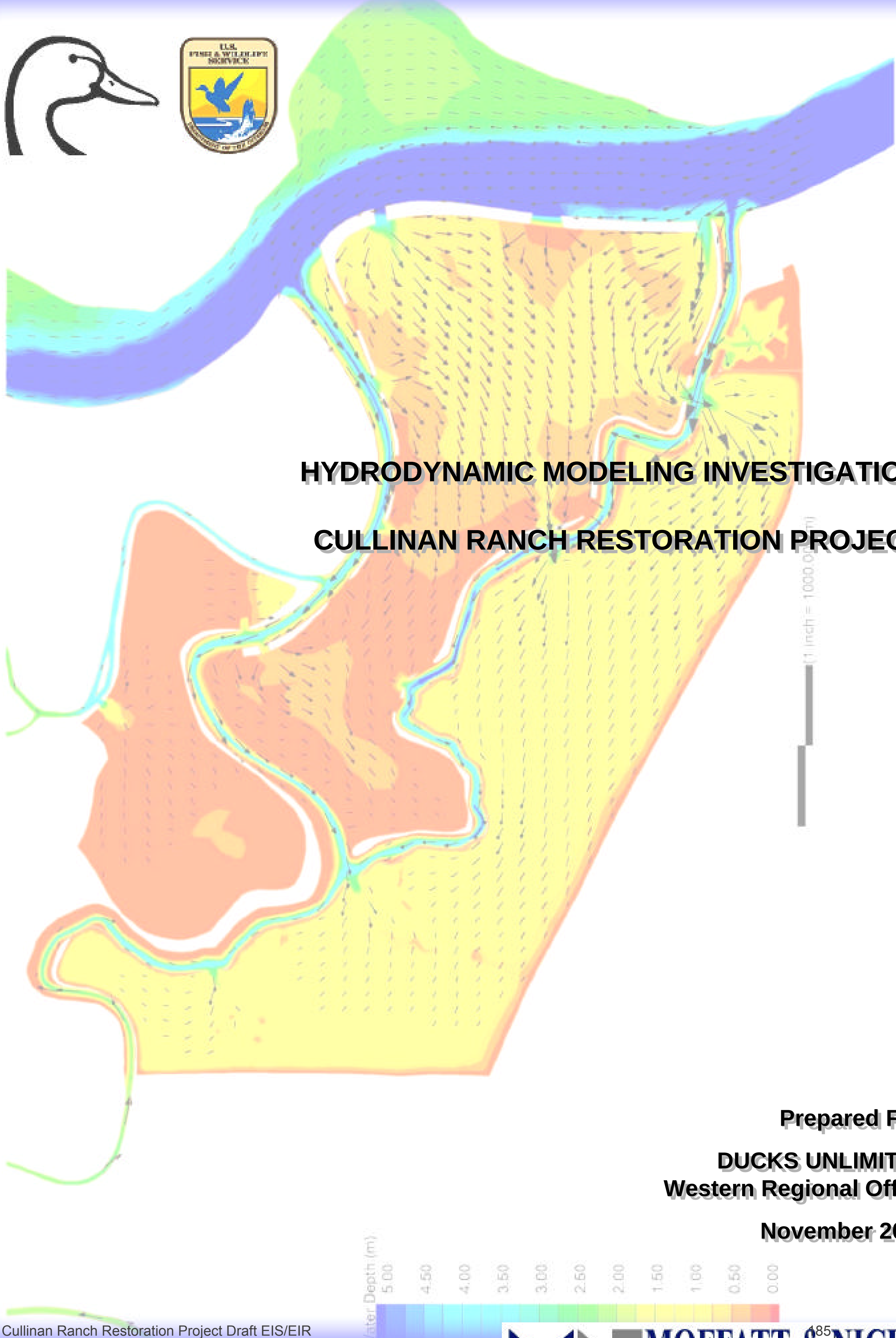
Appendix A
Hydrology Report



HYDRODYNAMIC MODELING INVESTIGATION

CULLINAN RANCH RESTORATION PROJECT

Prepared For:

DUCKS UNLIMITED
Western Regional Office

November 2004

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ENGINEERS

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SOLANO COUNTY, CALIFORNIA

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CONTENTS

CONTENTS .... **i**

TABLES .... **ii**

FIGURES .... **iii**

1 INTRODUCTION **1-1**

1.1 BACKGROUND 1-1
1.2 OBJECTIVE AND SCOPE OF WORK........ 1-1

2 SITE DESCRIPTION **2-1**

2.1 EXISTING CONDITIONS 2-1
2.2 HISTORIC CONDITIONS........ 2-2

3 RESTORATION OPTIONS **3-1**

3.1 OPPORTUNITIES AND CONSTRAINTS 3-1
3.2 EVALUATION APPROACH........ 3-1
3.3 RESTORATION OPTIONS CONSIDERED........ 3-2

4 NUMERICAL MODEL DEVELOPMENT **4-1**

4.1 MODEL BOUNDARIES AND GRID........ 4-1
4.2 BOUNDARY CONDITIONS AND MODEL CALIBRATION 4-2

5 ANALYSIS OF RESTORATION OPTIONS........ **5-1**

5.1 SIMULATION RESULTS - HYDRODYNAMICS 5-2
5.2 SEDIMENTATION........ 5-22
5.3 EXPECTED EVOLUTION OF HABITAT IN THE RESTORED AREAS........ 5-24

6 SUMMARY OF FINDINGS AND RECOMMENDATIONS **6-1**

6.1 SUMMARY OF FINDINGS 6-1
6.2 DISCUSSION AND RECOMMENDATIONS........ 6-1

7 REFERENCES........ **7-1**

TABLES

Table 2.1-1 Tidal Datum Information 2-2
Table 3.3-1 List of Restoration Options Considered 3-3
Table 5.1: Summary Of Simulation Cases 5-1
Table 5.1-1: Simulation Results For Case 1 (Existing Conditions) 5-3
Table 5.1-2: Simulation Results For Case 2 5-6
Table 5.1-3: Simulation Results For Case 3 5-8
Table 5.1-4: Simulation Results For Case 4 5-10
Table 5.1-5: Simulation Results For Case 5 5-12
Table 5.1-6: Simulation Results For Case 6 5-14
Table 5.1-7A: Simulation Results For Case 7a 5-16
Table 5.1-7B: Simulation Results For Case 7b 5-18
Table 5.1-8 Simulation Results For Case 8 5-20
Table 5.1-9 Channel Geometry at V1 near Mouth of Dutchman Slough 5-21
Table 5.2-1 Summary Statistics - Suspended Sediment In Dutchman Slough 5-22
Table 5.2-2 Restoration Timeline For Low Marsh Plain Colonization 5-23
Table 6.1-1: Summary Of Water Levels - All Options 6-3
Table 6.1-2: Summary Of Peak Velocities - All Options 6-4

FIGURES

Figure 2.1 - 1 Location Map

Figure 2.1 - 2 Vicinity Map

Figure 2.1 - 3 Site Elevations (feet, NGVD29)

Figure 2.1 - 4 Existing Tidal Phase

Figure 2.2 - 1 Historical Marsh

Figure 2.2 - 2 Dutchman Slough Cross Sections (See Figure 4.1 - 1 for Locations)

Figure 2.2 - 3 South Slough Cross Sections (See Figure 4.1 - 1 for Locations)

Figure 3.3 - 1 Case 2: Full Restoration – Five Breaches (Pre-Pond 3 Construction)

Figure 3.3 - 2 Case 2 Variant: Full Restoration – Five Breaches, Dutchman Slough Mouth Widened/Deepened (Pre-Pond 3 Construction)

Figure 3.3 - 3 Case 3: Full Restoration – Two Breaches on West Side (Pre-Pond 3 Construction)

Figure 3.3 - 4 Case 4: Partial Restoration – 300 Acres, East (4a) or West (4b) (Pre-Pond 3 Construction)

Figure 3.3 - 5 Case 5: No Action (Post-Pond 3 Construction)

Figure 3.3 - 6 Case 6: Partial Restoration – 300 Acres, West (Post-Pond 3 Construction)

Figure 3.3 - 7 Case 7: Full Restoration – Two Breaches on West Side (Post-Pond 3 Construction)

Figure 3.3 - 8 Case 8: Full Restoration – Four Breaches (Post-Pond 3 Construction)

Figure 4.1 - 1 Model Domain and Bathymetry

Figure 4.1 - 2 Model Calibration & Validation

Figure 5.1 - 1 Simulated Water Levels, Case 1: Existing Condition

Figure 5.1 - 2 Simulated Flow Field - Peak Ebb at Mouths of Dutchman/South Sloughs, Case 1: Existing Condition

Figure 5.1 - 3 Simulated Water Levels, Case 2: Full Restoration - Five Breaches (Pre-Pond 3 Construction)

Figure 5.1 - 4 Simulated Flow Field - Peak Ebb at Mouths of Dutchman/South Sloughs, Case 2: Full Restoration - Five Breaches (Pre-Pond 3 Construction)

Figure 5.1 - 5 Simulated Water Levels, Case 3: Full Restoration - Two Breaches on West (Pre-Pond 3 Construction)

Figure 5.1 - 6 Simulated Flow Field - Peak Ebb at Mouths of Dutchman/South Sloughs, Case 3: Full Restoration - Two Breaches on West (Pre-Pond 3 Construction)

Figure 5.1 - 7 Simulated Water Levels, Case 4a: Partial Restoration – 300 Acres on East Side (Pre-Pond 3 Construction)

Figure 5.1 - 8 Simulated Flow Field - Peak Ebb at Mouths of Dutchman/South Sloughs, Case 4a: Partial Restoration – 300 Acres on East Side (Pre-Pond 3 Construction)

Figure 5.1 - 9 Simulated Water Levels, Case 4b: Partial Restoration – 300 Acres on West Side (Pre-Pond 3 Construction)

Figure 5.1 -10 Simulated Flow Field - Peak Ebb at Mouths of Dutchman/South Sloughs, Case 4b: Partial Restoration – 300 Acres on West Side (Pre-Pond 3 Construction)

Figure 5.1 -11 Simulated Water Levels, Case 5: No Action (Post-Pond 3 Construction)

Figure 5.1 -12 Simulated Flow Field - Peak Ebb at Mouths of Dutchman/South Sloughs, Case 5: No Action (Post-Pond 3 Construction)

Figure 5.1 -13 Simulated Water Levels, Case 6: Partial Restoration – 300 Acres on West Side (Post-Pond 3 Construction)

Figure 5.1 -14 Simulated Flow Field - Peak Ebb at Mouths of Dutchman/South Sloughs, Case 6: Partial Restoration – 300 Acres on West Side (Post-Pond 3 Construction)

Figure 5.1 -15 Simulated Water Levels, Case 7a: Full Restoration – Two Breaches on West Side (Post-Pond 3 Construction, Initial Condition)

Figure 5.1 -16 Simulated Flow Field - Peak Ebb at Mouths of Dutchman/South Sloughs, Case 7a: Full Restoration – Two Breaches on West Side (Post-Pond 3 Construction, Initial Condition)

Figure 5.1 -17 Simulated Water Levels, Case 7b: Full Restoration – Two Breaches on West Side (Post-Pond 3 Construction, Interim Condition)

Figure 5.1 -18 Simulated Flow Field - Peak Ebb at Mouths of Dutchman/South Sloughs, Case 7b: Full Restoration – Two Breaches on West Side (Post-Pond 3 Construction, Interim Condition)

Figure 5.1 -19 Simulated Water Levels, Case 8: Full Restoration – Four Breaches (Post-Pond 3 Construction, Interim Condition)

Figure 5.1 -20 Simulated Flow Field - Peak Ebb at Mouths of Dutchman/South Sloughs, Case 8: Full Restoration – Four Breaches (Post-Pond 3 Construction, Interim Condition)

Figure 5.1 -21 Erosion of Dutchman Slough near Mouth Case 8: Full Restoration – Four Breaches (Post-Pond 3 Construction)

Figure 5.2 - 1 Marsh Accretion at Cullinan Ranch

1 INTRODUCTION

1.1 BACKGROUND

The Cullinan Ranch restoration project would restore approximately 1,500 acres of diked baylands back to tidal conditions by reintroducing tidal flow into the project area. The objective of reintroducing tidal flow is to recreate historic salt marsh habitat for the benefit of endangered species, as well as migratory water birds.

The proposed restoration is based on the concept that reintroducing tidal waters and capturing available sediment in the water column will raise site elevations with the final stage being salt-water marsh habitat conditions. Incoming tides would bring suspended sediment from Napa River and San Pablo Bay, which would deposit in the restoration site because of reduced tidal currents, building up site elevations. Continued tidal action would develop tidal channels, and maintain an active exchange of water, sediment, and nutrients between the marsh habitat and the Bay, further enhancing the value of the habitat for plants and wildlife.

Ducks Unlimited (DU) is assisting with preliminary engineering and environmental documentation as part of a grant from CALFED for the Cullinan Ranch restoration project. As part of the alternatives analysis, hydrodynamic impacts to the adjacent sloughs need to be assessed. This report presents the results of hydrodynamic modeling analyses of water levels and circulation, and geomorphic analysis to assess marsh evolution and the restoration timeline for the various options developed by the project team. Results were used to evaluate scour potential in adjacent sloughs, and to develop mitigation measures.

1.2 OBJECTIVE AND SCOPE OF WORK

The purpose of this study is to analyze hydrodynamic and geomorphic characteristics for the various restoration options, evaluate the potential for channel scour at the adjacent sloughs due to the project, and assess the restoration timeline.

Specific scope items included:

1. **Develop Details of Restoration Options.**

   DU had prepared a preliminary set of alternatives for the restoration project. Based on discussions with DU, additional restoration options were developed for this study. These options were developed with the objectives of maximizing sediment retention, minimizing impacts to adjacent sloughs and property, and minimizing the need for future maintenance. Initial and future construction costs were also considered in developing the restoration options. The primary variables considered in developing the restoration options were: 1) Size of restoration ; 2) Need for future maintenance activities; and 3) Impacts of/to other ongoing projects and local hydrology. Based on these variables, several restoration options were developed for further evaluation.

2. **Obtain Additional Data**

   As part of the Guadalcanal Village Wetlands design phase, Dutchman Slough was surveyed in 1999. Cullinan Ranch was also surveyed by Towill, Inc. in 1993. Additional cross sections were surveyed along South Slough by Environmental Data Solutions in January 2004, and elevations for Ponds 2A and 3 were obtained from the California Department of Fish and Game (CDFG).

3. **Develop Numerical Model**

   This task included developing a two-dimensional numerical hydrodynamic model for the project area, which included Cullinan Ranch, Pond 2A, Pond 3, Dutchman Slough, South Slough, portion of Napa River, and other sloughs between Sonoma Creek and Napa River.

4. **Conduct Simulations**

   This task included conducting hydrodynamic simulations for existing conditions and the restoration options, and evaluating effects on local hydrology.

5. **Geomorphic Processes**

   This task included a geomorphic analysis of the restoration options, to address marsh evolution patterns and rates within Cullinan Ranch. Future channel form and dimensions for Dutchman Slough and South Slough were also estimated.

6. **Report and Presentation**

   This task included documenting results of the modeling and analyses, and presenting findings and recommendations.

2 SITE DESCRIPTION

2.1 EXISTING CONDITIONS

Cullinan Ranch is a 1500-acre parcel that is bordered by the South and Dutchman Sloughs to the north and State Route 37 to the south. CDFG's Pond 1 borders Cullinan Ranch to the west. Guadalcanal Village Wetlands (Guadalcanal), which was restored by Caltrans, borders Cullinan Ranch to the east. The existing perimeter levee provides flood protection from the adjacent sloughs. Location and vicinity maps are provided on Figures 2.1-1 and 2.1-2.

The site is located in an area of the Napa River Delta that was historically defined by a network of meandering sloughs and extensive estuarine tidal marshes. The site was diked off in the early 1900's, drained, and used for agricultural purposes (oat & hay farming) up to 1991 when it was acquired by the Fish & Wildlife Service. Draining the land has resulted in subsidence by as much as six feet; presently the site is not being drained and seasonal ponding occurs in several areas.

The average existing land elevation based on the 1993 survey is about -2 ft NGVD. A topographic map is presented in Figure 2.1-3. Some areas (such as drainage ditches and historical channels) are lower than -3 ft NGVD. The average elevation of the perimeter levees is + 6 ft, which provides adequate flood protection. However, several segments of the flood protection levee along Dutchman Slough are experiencing erosion, which has required periodic armoring with rock to stabilize the slopes and prevent accidental breaching. The last episode of armoring occurred in 2003, approximately midway between the mouth of Dutchman Slough and the confluence with South Slough, where the channel was excavated in the early 1900's to build the levee. The Highway 37 levee along the southern boundary varies in elevation from +6 feet near Guadalcanal to +10 feet near the westerly limit of the site.

The existing tidal range along Dutchman Slough and South Slough is about the same between Napa River and the westerly limit of the site (no damping observed), because South Slough is also connected to San Pablo Bay via Napa Slough and Sonoma Creek. Tidal datums from two tide gages in the vicinity (Mare Island Naval Shipyard, Carquinez Strait, CA 9415218, and Edgerly Island, Napa River, CA 9415415) are presented in Table 2.1-1. The local sloughs experience a spring tide range of 5.9 feet, with a high water of about 3 feet above NGVD, which also coincides approximately with the elevation of the high fringe marshes in the area.

A tidal phase lag of about 20 minutes at high water exists between the mouth of Dutchman Slough and the westerly limit of the site (Warner et. al., 1999). The convergence zone (where high waters from Napa River and Napa Sloughs meet) is near the westerly limit of the site. Tides propagate from the mouth of Sonoma Creek and the mouths of Dutchman and South Slough and meet in South Slough just west of the project western boundary (Figure 2.1-4).

Currents, temperature, salinity, and suspended sediment concentrations in the local sloughs were also measured by USGS (Warner et. al. 1999) over a 1 year period in 1998. Peak tidal currents in Dutchman Slough are in the range of 0.8 ft/s to 1.8 ft/s (ebb dominant). Suspended sediment concentrations are highly dependent on water levels and fresh water outflow from the Napa and Sonoma watersheds and the Delta, and vary from 50 mg/l to 750 mg/l in the winter.

Table 2.1-1 Tidal Datum Information

Tidal Plane	Mare Island, CA 9415218	*Edgerly Island, CA 9415415
Highest Observed Water Level	5.32 ft (12/96)	---
Mean Higher High Water (MHHW)	3.54 ft	3.85 ft
Mean High Water (MHW)	2.98 ft	3.15 ft
Mean Tide Level (MTL)	0.81 ft	---
National Geodetic Vertical Datum – 1929 (NGVD)	0.00 ft	0.00 ft
Mean Low Water (MLW)	-1.36 ft	-1.59 ft
Mean Lower Low Water (MLLW)	-2.32 ft	-2.45 ft
North American Vertical Datum – 1988 (NAVD)	-2.74 ft	---
Lowest Observed Water Level	-3.98 ft (4/86)	---

* Estimated

The restoration of 55 acres at Guadalcanal occurred in 2000 by Caltrans, and the hydrodynamic model of the area (Moffatt & Nichol 1999) was refined and used in this study. Several alternatives were investigated as part of the Guadalcanal restoration efforts, some of which envisioned the restoration of Cullinan Ranch. As a result, a high breach (at mean high water) between Guadalcanal and Cullinan Ranch was constructed to allow a future connection between the 2 restoration sites.

2.2 HISTORIC CONDITIONS

Cullinan Ranch was formerly part of a large tidal wetland complex along the lower Napa River (See Fig. 2.2-1). The original marsh was separated from San Pablo Bay by a wave-built barrier beach along the shore of the bay, near the present alignment of Highway 37. The pulse of sediment from 19th century hydraulic mining in the Sierra contributed to the growth of the present wetland fringe south of the highway (Johnson et al., 1994).

Before the diking of the Ranch area *ca*. 1900, Dutchman Slough was poorly connected to what is now called South Slough (formerly Navy Yard Slough). The present connection of Dutchman Slough with South Slough probably dates from around the time of the diking of the remaining marshes for agriculture.

Conditions changed dramatically after levee construction in the early 1900's. Ponds 1, 2/2A, 3 and Cullinan Ranch were isolated from the tidal regime by these perimeter levees. Dutchman Slough was dredged and extended to connect to South Slough. This reduced the total prism in South Slough and Dutchman Slough significantly, and as a result South Slough silted in, and fringe marshes along the channel developed naturally. An aerial photo from April 2002 (Figure 2.1-2) shows that the South Slough channel width has greatly reduced, and an extensive fringe marsh has developed along its banks. Although South Slough was historically the dominant connector channel between Napa River and Sonoma Creek, the diking and excavation activities, including sedimentation in South Slough, have resulted in Dutchman Slough presently being the dominant connector channel.

Since the diking of Cullinan Ranch for oat and hay farming, the area has subsided due to oxidation and desiccation of the peat-rich soils. In 1991 the area was acquired by the U.S. Fish and Wildlife Service for inclusion in the San Pablo Bay National Wildlife Refuge. The new owners stopped pumping from most of the area, and the subsequent rise in water table and ponding of surface water has facilitated invasion by cattails (*Typha sp.*) and other wetland plants.

As described above, South Slough and Dutchman Slough has experienced dramatic changes in recent history. Recent survey data indicate that the Dutchman Slough near its entrance is more or less under an equilibrium status with no significant changes on cross sectional area being observed from the 1999 and 2004 surveys. However, near the west end of the Dutchman Slough, the channel cross section area seems slightly reduced (see Figure 2.2-2), which indicate that sediment is still accumulating in this area.

South Slough, especially east of China Slough, has experienced some erosion based on the 1999 and 2004 survey data (see Figure 2.2-3). The cross sectional area for the western portion of South Slough near its confluence with Dutchman Slough seems relatively unchanged, although the channel is dynamically shifting position between the Pond 2A and Pond 3 levees. The erosion of South Slough is most likely a result of the increased tidal prism from the restoration of Pond 2A and the accidental levee breach along the north side of Pond 3 to South Slough.

3 RESTORATION OPTIONS

3.1 OPPORTUNITIES AND CONSTRAINTS

The overall goal of the Cullinan Ranch Restoration Project is to restore the site to its original state of a complex tidal marsh, and provide vital habitat for plant, fish, bird and other wildlife species, including endangered species such as salt marsh mouse and California clapper rail. The acquisition of the Napa Sonoma Salt Ponds by CDFG, planned restoration efforts in the immediate vicinity (Pond 3 and American Canal), and closure of the Mare Island Naval Shipyard which has reduced the need for maintenance dredging of Napa River provide excellent opportunities for restoration of Cullinan Ranch and re-creation of tidal marsh habitat for endangered species and shorebirds.

The primary constraints associated with the restoration project are:

1. **Flood Protection:** Opening Cullinan Ranch to tidal influence will require providing flood protection to the Highway 37 levee and Pond 1 levee. Associated levee improvements and maintenance, to protect from overtopping and wave induced erosion has to be considered.
2. **Subsidence:** The site has subsided by 5 to 6 feet since the early 1900s due to diking and agricultural activities. Significant amounts of sediments are required, in a manner that promotes habitat diversity, to restore site elevations back to elevations suitable for tidal marsh habitat.
3. **Site Hydrology:** Once the levee is breached, low site elevations will create a large basin which will substantially increase the tidal prism of Dutchman and South Sloughs. The increased prism and resultant higher tidal currents may result in channel erosion and loss of fringe marshes in the slough system. Pritchard Marsh, which is located on the south bank of Dutchman Slough near its mouth, may also see erosion due to the combined effect of the Ranch and Pond 3 restoration projects. The potential for release of contaminants from Pritchard Marsh may be a concern which would have to be addresses.
4. **Water Quality:** Circulation and water quality may be an issue because the site will not completely drain out even at low tide due to subsidence. Low flushing rates and potentially stagnant pools of water may be a concern which would have to be addressed in the design.
5. **Ongoing Restoration Activities:** The cumulative effect of ongoing and future projects (Napa Sonoma Marsh, American Canal, etc.) on local hydrology are at least as significant as the Ranch project, and need to be examined together with the Cullinan Ranch. This requires an assessment of the synergistic relationships between the Ranch project and the other projects.

Each of the above constraints need to be taken into account when developing restoration options. The restoration options described in the next section were developed in a staged manner, based on modeling and analytical assessments of the above constraints.

3.2 EVALUATION APPROACH

For a simple geometry and flow condition it is possible to evaluate the hydrodynamic properties of a water body using analytical and empirical methods. However, for unsteady tidally driven flow conditions and complex geometries like the Napa Marsh area where several sloughs interconnect and affect hydrodynamics, simple analytical methods are not appropriate for representation of spatial and temporal variations. Also, the differences between construction features of the different restoration options are not dramatic, which makes comparisons between options using analytical solutions difficult to predict. Numerical modeling is by far the most practical and cost-effective tool to analyze hydrodynamics, make assessments of geomorphic changes to a slough channel system and evaluate differences between restoration options.

Numerically simulating the existing hydrodynamics of the Dutchman Slough, South Slough, and Napa River system resulted in a better understanding of circulation, water levels, and tidal currents, and allowed for development of the options described below.

3.3 RESTORATION OPTIONS CONSIDERED

The restoration options were developed in a phased manner based on results of each successive modeling run. The original design concept of 5 breaches from Dutchman Slough to the Ranch site (as presented by DU in preliminary discussions) was first analyzed, which produced significant tidal damping within the restoration site and vicinity coupled with high channel velocities. Restoration options were developed to reduce these effects by adjusting size and location of restoration, varying the number and size of breaches, and widening Dutchman Slough near its mouth. These options were initially analyzed assuming that the implementation schedule for restoration of Cullinan Ranch would precede that of Ponds 3, 4 and 5. Even if the restoration of Ponds 3, 4, and 5 were to precede that of Cullinan, it would be necessary to identify the effects of the Ranch restoration project by itself ("filter" out the effects of Ponds 3, 4, and 5 restoration).

Based on subsequent discussions, it was determined that CDFG's implementation schedule for proposed restoration of the Napa Sonoma Salt Ponds may very well result in Ponds 3, 4 and 5 being restored prior to the Cullinan Ranch project. Therefore, the interaction between the two projects had to be factored in the modeling effort, and a few of the options were simulated assuming Ponds 3, 4 and 5 were restored prior to restoration of the Ranch site. Since Ponds 4 and 5 were sufficiently removed from the Dutchman Slough vicinity (ponds breach into China Slough and Napa River), it was determined that including only Pond 3 in the Cullinan Ranch numerical model would be sufficient for this planning effort. The cumulative hydrodynamic effects of restoring Ponds 3, 4 and 5, particularly near the mouth of South Slough, will be slightly larger than those presented in this report because of the additional tidal prism that would come through China Slough. Consequently, the portion of total scour near the mouth of South Slough that is attributed to the Cullinan Ranch project would be slightly lower than that shown in this study.

The restoration options described below are only a subset of the project alternatives described in the EIS/R for the Cullinan Ranch project, and the numbering scheme shown below does not match the scheme in the EIS/R. Restoration options were selected based on the following considerations:

- NEPA/CEQA requirements – (No Action Cases for Existing and Cumulative Impact Analysis);
- Minimize hydrodynamic changes to vicinity – (adjust size of restoration and/or breach design to minimize scour and damping)
- Scheduling - (status of Napa Salt Pond restoration)

Based on the above considerations, the following options were developed and analyzed using a numerical hydrodynamic model. The actual simulation case numbers that each of the restoration options represent, and reference to a figure describing the option, are also provided in Table 3.3-1. The rationale behind each restoration option, and details of the options themselves are described in the Section 5.

A description of the numerical model and simulation results for each of the cases described in Table 3.3-1 are provided in the following sections.

Table 3.3-1 List of Restoration Options Considered

Description	**Simulation Case (Reference Figure)**
Existing Conditions (Pre Pond 3 Construction)	
No Action (Existing Conditions)	Case 1 (see Figure 2.1-2)
Full Restoration – Vary breach size to limit tidal prism	Case 2 (see Figure 3.3-1)
Full Restoration – Widen mouth of Dutchman Slough through Pond 3 to reduce erosion potential	Case 2a (see Figure 3.3-2)
Full Restoration – Limit number of breaches to limit increase in tidal prism	Case 3 (see Figure 3.3-3)
Partial Restoration – Restore 300 acres along east side of site only	Case 4a (see Figure 3.3-4)
Partial Restoration – Restore 300 acres along west side of site only	Case 4b (see Figure 3.3-4)
Cumulative Impacts (Post Pond 3 Construction)	
No Action - Pond 3 restored, but no breaches to D.S.	Case 5 (see Figure 3.3-5)
Partial Restoration - Pond 3 restored, but no breaches to D.S., Restore 300 acres along west side of site only	Case 6 (see Figure 3.3-6)
Full Restoration - Fully integrated with Pond 3 - Limit number of breaches to limit increase in tidal prism - Conditions immediately following breaching (Initial Conditions) - Conditions in the near future (Interim Conditions)	Case 7a (see Figure 3.3-7) Case 7b (see Figure 3.3-7)
Full Restoration – Fully integrated with Pond 3 - Conditions in the near future (Interim Conditions)	Case 8 (see Figure 3.3-8)

4 NUMERICAL MODEL DEVELOPMENT

4.1 MODEL BOUNDARIES AND GRID

A numerical model for the area, using the Danish Hydraulic Institute's two-dimensional vertically averaged hydrodynamic module MIKE21-HD, was developed at the beginning of this study. This model was refined using the *Guadalcanal Model (GM)* which was developed as part of design efforts for Caltrans (Moffatt & Nichol 1999). The model uses a rectangular grid, and a uniform resolution of 6 meters covering the project site, Dutchman Slough, and South Slough above its confluence with Dutchman Slough was selected. The initial restoration options presented by DU (Cases 1 through 4, full restoration prior to Pond 3 construction) were simulated using this model. The model did not include Pond 2A because of inadequate bathymetry and flow data at the time the model was constructed.

As more information was obtained, it became clear that a larger model domain including not only the project site, but also other sloughs within the Napa-Sonoma area and CDFG salt ponds 2A and 3 was needed. A finite element model, which is much more conducive to meandering sloughs and varying spatial resolution, was therefore developed using the RMA-2 suite of programs. Similar to a finite difference model, the finite element model solves the fully time-dependent continuity and momentum equations, and simulates water level variations and flows in response to a variety of forcing functions in water bodies. Water levels and flows in RMA-2 are resolved on a 2-dimensional mesh with variable mesh size, which allows refined resolution in areas of interest such as within sloughs while keeping a coarser resolution in areas that do not need the same level of detail. This allows for a greater level of flexibility and computational efficiency.

The *Cullinan Ranch Model (CRM)* includes Cullinan Ranch, Ponds 2A and 3, Dutchman Slough, South Slough, portions of Napa River, and the tidal sloughs between Sonoma Creek and Napa River. The existing channel bathymetry and site elevation data were obtained from many sources including :

- NOAA nautical charts;
- Cullinan Ranch topographic survey by Towill (1993);
- Dutchman Slough hydrographic surveys by Sea Surveyor (1999) and EDS (2004);
- South Slough hydrographic surveys by Towill (2000) and EDS (2004);
- Ponds 2A and 3 topographic survey by Towill (1999-2000)

These data was used to create the model bathymetry with a varying mesh size from 5 m to 200 m. The model open boundaries were selected at Napa River downstream of the Highway 37 bridge, and at the mouth of Sonoma Creek in San Pablo Bay. Time series water surface elevations were applied at these open boundaries, as the primary forcing function, to drive the model. Measured water level data for Dutchman Slough existed from the Guadalcanal design efforts (Moffatt & Nichol 1999), which was used to calibrate the model. Figure 4.1-1 shows the details of the *CRM* model, including topography, bathymetry, and the output stations used for comparison purposes.

Almost all of the simulation cases, including the ones which were analyzed using the MIKE model, were analyzed again for comparison purposes.

4.2 BOUNDARY CONDITIONS AND MODEL CALIBRATION

The model was developed based on several sources of data, which were used for model calibration, validation, and conducting simulations of the various restoration options. Cullinan Ranch was surveyed in 1993 as part of the acquisition; Dutchman Slough was surveyed in 1999 as part of the Guadalcanal planning efforts and again in 2004 for comparison purposes; South Slough was surveyed in 2000 as part of the Napa Sonoma Salt Pond planning efforts and again in 2004 for comparison purposes.

As part of the Guadalcanal Village Wetlands design phase, 3 tide gages were installed and water surface elevations were recorded for a 30-day period in March 1999. The locations of these tide gages in Dutchman Slough were 1) near the mouth of the Slough in Napa River, 2) near the Guadalcanal Village site (near P2 in Figure 4.1-1), and 3) near its confluence with South Slough (near P6 in Figure 4.1-1). In addition, water surface elevation and current speed data measured by UC Davis (John C. Warner, et. al., 1999) were also used in this study to validate model performance.

The RMA-2 model was calibrated by comparing simulated and measured water surface elevations near points P2 and P6. Three days of near-spring tides (3/20/99 to 3/23/99) and three days of neap tides (3/7/99 to 3/10/99) were selected as model calibration and validation periods. The model was calibrated by adjusting bed resistance, viscosity, and other model parameters.

Simulated water surface elevations at P2 and P6 were compared to the measured water levels (see Figure 4.1-2), which were found to be in good agreement. The Guadalcanal gage was exposed at tides lower than MLW, because the gage had to be placed away from the channel thalweg due to navigation reasons. As a result, the model validation shows tide levels which are truncated at low tide. The magnitude of tidal currents were verified by comparing simulated and measured current speeds at UC-Davis' monitoring station DUTCH, which is near V3 on Figure 4.1-1. There were datum conversion issues between UC Davis' data on tidal currents and simulated currents, so a complete comparison was not possible. However, the range and phase of currents were found to be in very close agreement.

Since normal flows in Napa River were not found to contribute significantly to water levels and/or currents in Dutchman Slough, a no-flow boundary condition near the City of Napa was assumed. Wind induced shear was not included in the modeling of hydrodynamics because, for typical conditions, the effects of wind on circulation and water levels at the project site are generally small compared to the effects of tidal forcing. For modeling of sedimentation and water quality, wind becomes a significant parameter to include in the model.

A synthesized time series, which matched long term water level statistics shown on Table 2.2-1, was developed for numerical simulations of the alternative restoration options. Compared to the model domain the model resolution was relatively fine, and a full spring-neap tide cycle was computationally not practical to simulate. A 3.5 day time series, which resulted in a MHHW of 3.8 ft NGVD and a MLLW of –2.5ft NGVD, was selected as the typical tide for the model boundary conditions. Initial conditions were set at high tide water level and a zero velocity field. One tidal period (approximately 12 hours) was found to be adequate to "spin-up" the model and eliminate discrepancies in water levels within the model domain. The actual simulation period was therefore about 3 days, plus a 0.5 day model spin-up period.

5 ANALYSIS OF RESTORATION OPTIONS

As described in Section 3, several restoration options and some variants within each option were developed for analysis (see Table 3.3-1). The simulation cases, along with details used in developing the model bathymetry are summarized in Table 5.1.

Table 5.1 Summary of Simulation Cases

Case	Description	Bathymetry Used in Simulations
Existing Conditions (Pre Pond 3 Construction)		
1	**No Action** (Existing Conditions)	Base case using existing slough geometry / bathymetry
2	**Full Restoration** – Vary breach size to limit tidal prism	Use 5 breaches per original concept, vary breach sizes - 400 ft, 200 ft, and 100 ft
2a	**Full Restoration** – Widen mouth of Dutchman Slough through Pond 3 to reduce erosion potential	Use 5 breaches per original concept, breach size 400 ft, widen/deepen Dutchman Slough mouth through Pond 3
3	**Full Restoration** – Limit number of breaches to limit increase in tidal prism	Use only 2 breaches along the western portion of the site where levee maintenance is highest
4a	**Partial Restoration** – Restore 300 acres along east side of site only	Construct new levee in north-south direction, restore eastern portion along Guadalcanal, breach size 400 ft
4b	**Partial Restoration** – Restore 300 acres along west side of site only	Construct new levee in north-south direction, restore western portion along Pond 1, breach size 400 ft
Cumulative Impacts (Post Pond 3 Construction)		
5	**No Action -** Pond 3 restored, but no breaches to D.S.	Include Pond 3 restoration concept based on Napa Salt Ponds EIS/R, but no breaches to Dutchman Slough
6	**Partial Restoration** - Pond 3 restored, but no breaches to D.S., Restore 300 acres along west side of site only	New levee in north-south direction. Include Pond 3 restoration concept based on Napa Salt Ponds EIS/R, no breaches to Dutchman Slough
7a	**Full Restoration** - Fully integrated with Pond 3 - Limit number of breaches to limit increase in tidal prism - Conditions immediately following breaching (Initial Conditions)	Use only 2 breaches along the western portion of the site where levee maintenance is highest. Include Pond 3 restoration concept based on Napa Salt Ponds EIS/R. Simulate post breaching conditions.
7b	- Conditions in the near future (Interim Conditions)	Same as 7a, with wider/deeper South Slough near its confluence with Dutchman)
8	**Full Restoration** – Fully integrated with Pond 3 - Conditions in the near future (Interim Conditions)	Use 4 breaches, breach size 400 ft. Include Pond 3 restoration concept based on Napa Salt Ponds EIS/R. Simulate interim conditions (wider/deeper South Slough near its confluence with Dutchman)

5.1 SIMULATION RESULTS - HYDRODYNAMICS

5.1.1 CASE 1 :– NO ACTION, PRE POND 3 CONSTRUCTION

This simulation is essentially the Existing Conditions case, albeit with the recent breaching of Pond 3 not included because of unknown breach geometry. However, it is not expected that hydrodynamics in Dutchman Slough would have changed since the recent Pond 3 breach, since the breach dimensions are small and it is located far enough away from Dutchman Slough. The small additional breach to Dutchman Slough near the mouth of the slough is not large enough to affect hydrodynamics either. Pond 2A, which was restored a few years ago, was not included in the MIKE model because of inadequate bathymetry and flow data at the time the model was constructed, but was included in the RMA-2 model (see Section 4.1).

Simulated water levels and peak velocities are presented in Table 5.1-1. Peak velocity is defined here as the maximum ebb tide velocity between MHHW and MLLW, near the center of the channel, averaged over the water column. The exceedence frequency for this velocity (percent time that the velocity is higher than this number) is about 5.4%. The point locations where results are presented are as shown on Figure 4.1-1. Time series of water levels for various locations are presented graphically on Figure 5.1-1, which shows that water levels in the study area range from +3.7 ft to +3.8 ft (NGVD datum) at high tide, and -2.4 to -2.5 ft NGVD at low tide. A flow field when velocities peak at the mouths of Dutchman and South Sloughs are presented on Figure 5.1-2, which shows that peak velocities near the mouths of Dutchman and South Sloughs are about 1.8 ft/s and 1.3 ft/s, respectively. Note that velocities in the figure are in metric units of m/s (per model output), while velocity units in Table 5.1-1 are in English units of ft/s

Estimates of the diurnal tidal prism (defined here as the volume of water exchanged between MHHW and MLLW tides) at various locations were also prepared, and used as indicators for changes in slough morphology. As an example, the tidal prisms at the mouths of Dutchman Slough and the South Slough were calculated as approximately 1000 acre-ft each. Based on empirical tidal prism – slough geometry relationships (Williams, 2002), the existing Dutchman and South sloughs seem to be larger than the calculated equilibrium condition. Equilibrium condition is defined as the area that is just adequate to convey the designated tidal prism. Along the westerly reach, Dutchman Slough seems to be approximately 40% larger than expected, while at the mouth near Napa River the slough is about 20% larger than expected. This indicates that the slough may still be experiencing deposition (due to loss of prism from diking), especially near its confluence with South Slough. The mouth of South Slough seems to indicate a similar phenomenon, but is probably due to the increase in prism from Ponds 2A and 3. In diked baylands it is not uncommon to see channel geometries larger than channels in mature marsh plains, primarily because the deposited sediments are of low shear strengths and are subject to scouring during episodic events.

Table 5.1-1: Simulation Results For Case 1 (Existing Conditions)

Water Levels

Location*		HW*	LW*	Range
		(ft, NGVD)		(ft)
Dutchman Slough	P1	3.8	-2.5	6.3
	P2	3.8	-2.5	6.3
	P3	3.8	-2.5	6.3
	P4	3.8	-2.5	6.3
	P5	3.8	-2.5	6.3
	P6	3.8	-2.5	6.3
South Slough	P22	3.8	-2.5	6.3
	P23	3.8	-2.5	6.3
	P24	3.8	-2.5	6.3
	P7	3.8	-2.5	6.3
	P8	3.8	-2.4	6.2
G.V.*	P10-P11	3.8	-2.5	6.3
C.R.*	P12-P21	---	---	---

* Notes:

See Figure 4.1-1 for location of points
HW – High Water Level
LW – Low Water Level
G.V. – Guadalcanal Village
C.R. – Cullinan Ranch

Velocities and Tidal Prism

Location*		Peak Velocity (ft/s)	Diurnal Tidal Prism (acre-ft)
Dutchman Slough	V1 / E2	1.8	1002
	V2	1.4	--
	V3 / E3	1.4	777
	V4 / E4	1.4	572
	V5 / E5	0.8	430
South Slough	V9 / E13	1.3	891
	V8 / E11	0.9	307
	V7 / E10	0.6	52
	V6 / E6	0.8	276
	P8 / E8	1.1	84

* See Figure 4.1-1 for location of points

5.1.2 CASE 2 :– FULL RESTORATION, VARY BREACH SIZE, PRE POND 3 CONSTRUCTION

Breaching the Cullinan Ranch levees will increase flow within Dutchman and South Sloughs, as tidal waters come in and leave via the breaches. If the increase in tidal prism is substantial, it will increase velocities in the Sloughs which may have an impact on the channel banks. The objective of varying the breach size was to examine the effects of different sizes on the existing tidal regime in adjacent sloughs, including water levels and current speeds, and assess if it is practical to control the effects experienced by the sloughs. A series of numerical simulations were conducted by varying the width of the proposed breaches, using 400 ft, 200 ft, and 100 ft.

Simulated water levels and peak velocities are presented in Table 5.1-2. Time series of water levels for the alternative with 400 ft breaches are also presented in Figure 5.1-3. Results indicate significant damping of tides along Dutchman Slough and South Slough, including within the restored site, immediately after breaching (up to 50% of the present tide range is lost near the confluence of the two sloughs). Simulated water levels at various locations within Cullinan Ranch have approximately the same magnitude and differ only slightly in the tidal phase (approximately 6 minutes, which is not discernible in the figure). Water levels in Guadalcanal Village are affected as well (damping of about 30% of the present tide range). The tidal damping is caused primarily because the existing sloughs are not large enough to convey the required flow from the restored site. Even in the damped condition, the tidal prism through the mouth of Dutchman Slough increases to about 3.5 times that of existing conditions (3700 acre-feet versus 1000 acre-feet).

Simulated water levels for reduced breach sizes are also summarized in Table 5.1-2, indicating that the amount of damping within South and Dutchman Sloughs is not as severe as for the 400 foot wide breaches. Within Cullinan Ranch itself, the damping under the 200 ft and 400 ft breach scenarios appears to be similar, but more damping occurs under the 100 ft breach scenario because the smaller breaches restrict tidal exchange. Although less tidal muting along Dutchman and South Sloughs is anticipated for the 100-ft breaches than for the larger breach sizes (about 40% damping is still expected), the smaller breach dimension would have to be maintained over time with armor protection and/or other structural means. Also, levee maintenance along the slough would have to continue so that uncontrolled breaches, which would defeat the design objective of limiting tidal damping, do not occur.

Simulated along-channel velocities, also summarized in Table 5.1-2 for the 400 ft case, indicate that the peak ebb velocity near the mouth of Dutchman Slough increases significantly (to about 3.5 times the existing condition), while the peak ebb velocity in the middle and west portion of Dutchman Slough decreases by 30% to 50% because of a lower tide range. This implies a potential for erosion near the mouth of Dutchman Slough, and deposition farther west. It is likely that the primary drainage channel from the Ranch will be within the Ranch site itself (draining out at the breach closest to Napa River). A snapshot of the flow field when velocities peak at the mouths of the sloughs are also presented graphically in Figure 5.1-4, which shows the high ebb velocities near the mouth of Dutchman Slough and low velocities (indicating poor circulation) within Cullinan Ranch. Comparing this figure to Figure 5.1-2, areas of potential deposition and/or erosion can be identified intuitively.

In South Slough, the maximum increase in velocity occurs near its confluence with Dutchman Slough, where water depth is presently about 3 ft at a MLLW tide. The peak ebb velocity increases to about 4 times the existing peak, which suggests that the shoal in this area will erode. Other parts of South Slough closer to its mouth should not see significant changes in velocity because the shoal near the confluence is acting as a hydraulic control.

However, as the shoal erodes, South Slough will convey larger tidal flows and will continue seeing larger velocities until equilibrium is achieved. This would be similar to historic conditions, as observed on surveys from *ca.* 1860, which indicated that South Slough was the dominant channel in the marsh system in this area.

Near the west end of the project site, which is presently a convergence zone with low velocities, the results show a two-fold increase in peak ebb velocity; But closer to the confluence with Dutchman, the velocity decrease by as much as 60%. This indicates that the convergence zone will move closer to the restored site, as more flow is drawn into the Ranch from the mouth of Sonoma Creek to the west.

Constructing smaller breaches reduce the above effects to some degree. The change in peak velocity (compared to existing conditions) for the 100 ft breach case at the mouths of Dutchman and South Sloughs is about 25% less than for the 400-foot breach case. However, the reduction is not significant enough to eliminate the potential erosion because the peaks are still about 2.5 times the existing peaks.

Case 2b – Similar To Case 2, But With A Larger Entrance Channel Through Pond 3

An additional restoration option was simulated using a bypass channel through Pond 3, along the north side of Dutchman Slough, which would effectively connect the lower portion of the Ranch site to Napa River (see Figure 3.3-2). The assumption was that a new leveed channel would be built in the lower portion of Pond 3 (note that this option assumes the Ranch site would be restored prior to Pond 3), with the primary objective being reducing the erosion potential for Pritchard Marsh. The channel was assumed to be about 450 ft wide, which is about the width of Dutchman Slough, and a depth of 3.5 feet below NGVD was used in the model. This option would also eliminate the need for significant levee maintenance of the Pond 3 levee at the channel bend where Dutchman Slough turns south (see Figure 3.3-2).

Simulation results indicate that tidal damping near the first breach (near Guadalcanal) will be less than 1 foot. The Ranch will still experience a spring tide range less than 4.5 feet, compared to 6.3 feet in Napa River, which is about 30% damping. Peak velocities are about 60% smaller than the unmitigated case (Case 2 above), but still higher than existing velocities.

Calculations indicate that to maintain velocities at the mouth of Dutchman close to existing values, the bypass channel would have to be deepened to about 15 feet below NGVD. With this channel, tidal flow through Dutchman Slough would remain about the same and the cross section would not change, which would reduce the potential for erosion in the Pritchard Marsh area. Deepening the bypass channel to 15 feet below NGVD would represent more than 2 times the present channel cross sectional area near the mouth of Dutchman Slough, yet it would not eliminate damping within Cullinan Ranch. Although it relieves the erosion potential for Pritchard Marsh, the high construction costs for this alternative (dredging and levee improvements) do not make it a very attractive option.

An alternative could be widening the mouth of Dutchman Slough, but this was not deemed to be an attractive option either because the shape of the new equilibrium channel would not eliminate the erosion potential at Pritchard Marsh. Also, the sections of levees near the channel bends would continue to experience significant bank erosion, requiring continued maintenance at a high cost.

Table 5.1-2: Simulation Results For Case 2

Water Levels

Location		400-ft Breaches				200-ft Breaches				100-ft Breaches			
		HW	LW	Range*		HW	LW	Range*		HW	LW	Range*	
		(ft, NGVD)		ft	% of ex	(ft NGVD)		ft	% of ex	(ft, NGVD)		ft	% of ex
Dutchman Slough	P1	3.7	-2.5	6.2	98%	3.7	-2.5	6.2	98%	3.7	-2.5	6.2	98%
	P2	3.3	-1.1	4.4	70%	3.4	-1.5	4.9	78%	3.5	-1.8	5.3	84%
	P3	3.1	0.1	3.0	48%	3.1	-0.8	3.9	62%	3.3	-1.3	4.6	73%
	P4–P6	3.1	0.0	3.1	49%	3.0	-0.3	3.3	52%	3.1	-0.9	4.0	63%
South Slough	P22	3.8	-2.5	6.3	100%	3.8	-2.5	6.3	100%	3.8	-2.5	6.3	100%
	P23	3.8	-2.4	6.2	98%	3.6	-2.0	5.6	89%	3.6	-2.2	5.8	92%
	P24	3.1	0.0	3.1	49%	3.0	-0.5	3.5	56%	3.2	-1.0	4.2	67%
	P7	3.1	0.0	3.1	49%	3.0	-0.3	3.3	52%	3.1	-0.9	4.0	63%
	P8	3.2	-0.3	3.5	56%	NIM*				NIM*			
G. V.	P10–P11	3.4	-1.1	4.5	71%	3.4	-1.6	5.0	79%	3.5	-1.9	5.4	86%
C. R.	P12–P21	3.1	0.0	3.1	---	3.1	-0.1	3.2	---	3.0	0.5	2.5	---

* <u>Notes:</u>

% of ex – Percent of existing
NIM – Not in MIKE model domain

Velocities and Tidal Prism (400 ft Breach Case)

Location		Maximum Velocity		Diurnal Tidal Prism	
		(ft/s)	% of ex.	(acre-ft)	% of ex.
Dutchman Slough	V1 / E2	6.4	356%	3679	367%
	V2	4.6	329%		
	V3 / E3	2.3	164%	1508	194%
	V4 / E4	1	71%	447	78%
	V5 / E5	0.4	50%	227	53%
South Slough	V9 / E13	1.5	115%	1001	112%
	V8 / E11	1.2	133%	475	155%
	V7 / E10	2.5	417%	416	800%
	V6 / E6	0.3	38%	71	26%
	P8 / E8	2.1	191%	615	732%

5.1.3 CASE 3 :– FULL RESTORATION, LIMIT NUMBER OF BREACHES, PRE POND 3 CONSTRUCTION

The objective of this option was to keep most of the restoration related effects to the western portion of the study area. The option assumes 2 breaches along the western portion of the site. This would potentially accomplish 3 purposes :

- reduce effects on Pritchard Marsh,
- eliminate need for levee maintenance in this area, and
- restore the use of South Slough as the dominant tidal channel in the study area

Simulated water levels and peak ebb velocities are summarized in Table 5.1-3. Time series of water surface elevations at selected locations are presented in Figure 5.1-5. Results show less damping near the mouth of Dutchman Slough compared to Case 2, but more damping along South Slough and the western portion of Dutchman Slough. About 10% damping (6 inches of full tidal range) is expected near Guadalcanal Village. However, the tidal range near the confluence of Dutchman and South Sloughs, including portions of South Slough along Pond 2A, is reduced to about 30% of existing conditions. Water levels within Cullinan Ranch are also muted to about 30% of the present tidal range in Dutchman Slough.

Simulated velocity patterns in the project area are presented in Figure 5.1-6. Peak velocities near the mouths of both sloughs are lower than for Case 2 (see points V1 and V9), but still higher than existing conditions. Peak velocities in both sloughs near the confluence are about 3.5 to 4 times higher than existing conditions, which indicates that South Slough will most likely see some erosion of the fringe marshes along the levees between China Slough and Dutchman Slough. Velocities in the middle portion of Dutchman Slough also increase to about 2.5 times that of existing conditions (points V3 and V4), which is higher than for the Case 2 option.

Results indicate that this option will potentially re-establish South Slough as the dominant channel in the project area, but it does not reduce the potential for erosion near Pritchard Marsh. Levee improvements along most of Dutchman Slough will need to be constructed because of increased velocities, and maintained until breaches can be constructed along the eastern portion of the site.

Table 5.1-3: Simulation Results For Case 3

Water Levels

Location		HW	LW	Range	
		(ft, NGVD)		(ft)	% of Ex.
Dutchman Slough	P1	3.8	-2.5	6.3	100%
	P2	3.6	-1.9	5.5	87%
	P3	3.4	-1.3	4.7	75%
	P4	3.1	-0.5	3.6	57%
	P5	2.7	0.5	2.2	35%
	P6	2.7	0.6	2.1	33%
South Slough	P22	3.7	-2.5	6.2	98%
	P23	3.7	-2.4	6.1	97%
	P24	2.7	0.6	2.1	33%
	P7	2.7	0.6	2.1	33%
	P8	2.9	0.3	2.6	42%
G.V.	P10-P11	3.6	-1.9	5.5	87%
C.R.	P12-P21	2.7	0.6	2.1	---

Velocities and Tidal Prism

Location		Peak Velocity		Diurnal Tidal Prism	
		(ft/s)	% of Ex.	(acre-ft)	% of Ex.
Dutchman Slough	V1 / E2	4.4	244%	2119	211%
	V2	3.3	236%		
	V3 / E3	3.5	250%	2053	264%
	V4 / E4	3.6	257%	1971	345%
	V5 / E5	2.8	350%	1942	452%
South Slough	V9 / E13	1.4	108%	957	107%
	V8 / E11	1.1	122%	470	153%
	V7 / E10	2.4	400%	430	827%
	V6 / E6	1	125%	496	180%
	P8 / E8	2.2	200%	658	783%

5.1.4 Case 4 :– Partial Restoration, 300-Acres, Pre-Pond 3 Construction

In order to limit the increase in velocities (and potential scour) in Dutchman Slough, this option considered restoring only a portion of the Ranch site. Separate simulations were conducted for a 300-acre restoration along the eastern portion of the site (Case 4a), and for a 300-acre restoration along the western portion of the site (Case 4b). Simulation results for both cases are presented in Table 5.1-4, which are discussed individually below. Both cases will require building of new levees to isolate the un-restored areas, and maintenance of levees along Dutchman Slough along the un-restored reach.

Case 4a – Restore 300 Acres Along Eastern Portion

Partial restoration along the eastern portion of the site, near Guadalcanal Village, does not affect water surface elevations in the project area (0.1 to 0.2 ft damping shown on Table 5.1-4). Time series of water levels at various points are shown on Figure 5.1-7, and a flow field when velocity peaks at the mouth of Dutchman Slough is shown on Figure 5.1-8. Peak velocities in the immediate vicinity of the restoration will increase by nearly 2 times (points V1 and V2), which is expected because the prism through the mouth of the slough will nearly double. Velocities in other areas will most likely reduce by 10% to 15%, as much of the flow from Dutchman Slough goes into the restored portion.

Case 4b – Restore 300 Acres Along Western Portion

Partial restoration along the western portion of the site, near Pond 1, results in a damping of about 15% in the vicinity of the confluence. Time series of water levels at various points are shown on Figure 5.1-9, and a flow field when velocity peaks at the mouth of Dutchman Slough is shown on Figure 5.1-10. Peak velocities near the confluence, and up to China Slough, increase nearly 3 times as a greater amount of flow is channelized through South Slough. Velocities in Dutchman Slough above the confluence go up 50% to 70% throughout the project area.

Table 5.1-4: Simulation Results For Case 4

Water Levels

Location		4a: East First				4b: West First			
		HW	LW	Range		HW	LW	Range	
		(ft, NGVD)		(ft)	% of Ex	(ft, NGVD)		(ft)	% of Ex.
Dutchman Slough	P1	3.8	-2.5	6.3	100%	3.7	-2.5	6.2	98%
	P2	3.8	-2.4	6.2	98%	3.7	-2.3	6	95%
	P3	3.8	-2.3	6.1	97%	3.7	-2.1	5.8	92%
	P4	3.8	-2.3	6.1	97%	3.7	-1.9	5.6	89%
	P5	3.8	-2.4	6.2	98%	3.7	-1.7	5.4	86%
	P6	3.8	-2.4	6.2	98%	3.7	-1.7	5.4	86%
South Slough	P22	3.8	-2.5	6.3	100%	3.8	-2.5	6.3	100%
	P23	3.8	-2.5	6.3	100%	3.8	-2.5	6.3	100%
	P24	3.8	-2.4	6.2	98%	3.7	-1.7	5.4	86%
	P7	3.8	-2.4	6.2	98%	3.7	-1.5	5.2	83%
	P8	3.8	-2.4	6.2	100%	3.7	-1.7	5.4	87%
G.V.	P10-P11	3.8	-2.4	6.2	98%	3.7	-2.3	6	95%
C.R.	P12-P21	3.8	-1.2	5	---	3.7	-1	4.7	---

Velocities And Tidal Prism

Location		East First				West First			
		Maximum Velocity		Diurnal Tidal Prism		Maximum Velocity		Diurnal Tidal Prism	
		(ft/s)	% of Ex	(acre-ft)	% of Ex.	(ft/s)	% of Ex.	(acre-ft)	% of Ex.
Dutchman Slough	V1 / E2	3.4	189%	2058	205%	2.7	150%	1613	161%
	V2	2.7	193%			2.2	157%		
	V3 / E3	1.2	86%	505	65%	2.4	171%	1413	182%
	V4 / E4	1.2	86%	312	55%	2.4	171%	1215	212%
	V5 / E5	0.7	88%	208	48%	1.8	225%	1101	256%
South Slough	V9 / E13	1.2	92%	841	94%	1.3	100%	942	106%
	V8 / E11	0.8	89%	292	95%	0.9	100%	359	117%
	V7 / E10	0.5	90%	50	98%	1.8	300%	256	492%
	V6 / E6	0.7	88%	157	57%	2.4	300%	1179	427%
	P8 / E8	0.9	82%	187	223%	1.6	145%	407	485%

5.1.5 CASE 5 :– NO ACTION, POND 3 PARTIAL CONSTRUCTION

This option was analyzed for the Cumulative Conditions portion of the EIS/R, and for identifying the effects of the Pond 3 restoration project. It assumes Pond 3 is restored, but with no breaches to Dutchman Slough. Simulation results are presented in Table 5.1-5, and time series of water surface elevations at selected locations are presented in Figure 5.1-11. Results show that water levels in the project area are not affected by restoring Pond 3, because of the relatively small increase in tidal prism (Pond 3 elevations are high) after the restoration.

The net increase in tidal prism is about 60% at the mouth of South Slough. Most of the increase in peak velocity (up to 2 times the existing peak) is limited to the portion of South Slough between the mouth and its confluence with China Slough. Dutchman Slough also experiences an increase in tidal prism (20% to 50%) as a result of the restoration, which in turn causes velocities to increase by a similar magnitude (points V1 through V5).

A flow field when velocities peak at the mouths of Dutchman and South Sloughs is presented in Figure 5.1-12.

Table 5.1-5: Simulation Results For Case 5

Water Levels

Location		H.W.	L.W.	Range	
		(ft, NGVD)		(ft)	% of Ex.
Dutchman Slough	P1	3.8	-2.5	6.3	100%
	P2	3.8	-2.5	6.3	100%
	P3	3.8	-2.5	6.3	100%
	P4	3.8	-2.5	6.3	100%
	P5	3.8	-2.5	6.3	100%
	P6	3.8	-2.5	6.3	100%
South Slough	P22	3.8	-2.5	6.3	100%
	P23	3.8	-2.5	6.3	100%
	P24	3.8	-2.5	6.3	100%
	P7	3.8	-2.5	6.3	100%
	P8	3.8	-2.4	6.2	100%
G.V.	P10-P11	3.8	-2.5	6.3	100%
C.R.	P12-P21	---	---	---	---

Velocities and Tidal Prism

Location		Maximum Velocity		Diurnal Tidal Prism	
		(ft/s)	% of Ex.	(acre-ft)	% of Ex.
Dutchman Slough	V1 / E2	2.3	128%	1229	123%
	V2	1.7	121%		
	V3 / E3	1.7	121%	1004	129%
	V4 / E4	1.7	121%	797	139%
	V5 / E5	1.2	150%	658	153%
South Slough	V9 / E13	2.1	162%	1424	160%
	V8 / E11	2.1	233%	684	223%
	V7 / E10	0.7	117%	45	87%
	V6 / E6	0.8	100%	220	80%
	P8 / E8	1.1	100%	118	140%

5.1.6 CASE 6 :– PARTIAL RESTORATION, 300-ACRES ALONG WESTERN PORTION, PARTIALLY INTEGRATED WITH POND 3

This option assumes a 300-acre restoration along the western portion, similar to Case 4b, but after the first phase of Pond 3 is implemented (no breaches to Dutchman Slough). Results are summarized in Table 5.1-6, and Figures 5.1-13 and 5.1-14 show results of the simulations.

Results for water levels are similar to Case 4b (pre-Pond 3 case), albeit with slightly more damping (3% to 5% more) near the confluence of Dutchman and South Sloughs, due to the Pond 3 project. Similarly, peak velocities are higher than for Case 4b (20% to 30% higher) and are directly related to the increase in tidal prism due to Pond 3 restoration.

To summarize, most of the velocity increase in South Slough between its mouth and the confluence with China Slough is a result of the Pond 3 project (and potentially Ponds 4 and 5). Most of the increase in Dutchman Slough, and in South Slough between Dutchman and China Sloughs, is a result of the Ranch project. The second phase of the Pond 3 restoration (breaching to Dutchman Slough) would occur only when the entire Ranch site can be restored.

Partial restoration of the eastern portion, integrated with Pond 3, was not simulated because the results are not expected to be substantially different than Case 5 (partial restoration of Pond 3 only). Restoration of the eastern portion would not meet one of the key project objectives (recreate historical conditions, when South Slough was the dominant tidal channel in the project area).

One of the significant concerns with both partial restoration options (eastern or western portion) is that levee maintenance along much of Dutchman Slough would have to continue, perhaps at a cost even higher than existing conditions.

Table 5.1-6: Simulation Results For Case 6

Water Levels

Location		H.W.	L.W.	Range	
		(ft, NGVD)		(ft)	% of Ex.
Dutchman Slough	P1	3.7	-2.5	6.2	98%
	P2	3.7	-2.3	6	95%
	P3	3.7	-2	5.7	90%
	P4	3.7	-1.7	5.4	86%
	P5	3.7	-1.5	5.2	83%
	P6	3.7	-1.4	5.1	81%
South Slough	P22	3.8	-2.5	6.3	100%
	P23	3.7	-2.4	6.1	97%
	P24	3.7	-1.3	5	79%
	P7	3.8	-1.2	5	79%
	P8	3.8	-1.4	5.2	84%
G.V.	P10-P11	3.7	-2.3	6	95%
C.R.	P12-P21	3.8	-1	4.8	---

Velocities and Tidal Prism

Location		Maximum Velocity		Diurnal Tidal Prism	
		(ft/s)	% of Ex.	(acre-ft)	% of Ex.
Dutchman Slough	V1 / E2	3	167%	1708	170%
	V2	2.3	164%		
	V3 / E3	2.6	186%	1520	196%
	V4 / E4	2.7	193%	1340	234%
	V5 / E5	2	250%	1232	287%
South Slough	V9 / E13	2.2	169%	1605	180%
	V8 / E11	2.5	278%	769	250%
	V7 / E10	1.5	250%	167	321%
	V6 / E6	2.4	300%	1127	408%
	P8 / E8	1.7	155%	405	482%

5.1.7 CASE 7A :– FULL RESTORATION, LIMIT NUMBER OF BREACHES, FULLY INTEGRATED WITH POND 3 – INITIAL CONDITIONS

Case 3 was re-analyzed under the condition that the first phase of Pond 3 is implemented prior to the Ranch project, and the second phase along with the Ranch project. The simulation results are summarized in Table 5.1-7A. Simulated time series water levels at selected locations, and a snapshot of flow field when velocities peak at the mouth of Dutchman Slough are presented in Figures 5.1-15 and 5.1-16.

Results show that in general water levels are similar to those for Case 3. Tidal damping ranges from about 2% near the mouths of both sloughs to about 60% near their confluence. Water levels inside Cullinan Ranch are also muted, to about a 2.2 foot spring tide range. Water levels within Pond 3 will not be damped as much (less than 10% damping), primarily because the breaches are closer to the tidal source, Napa River.

Peak velocities in Dutchman and South Sloughs increase significantly, especially near their confluence (2 to 3.5 times existing conditions). The Pond 2A and Pond 3 levees along South Slough (between Dutchman and China Sloughs), and Dutchman Slough levees will be stressed by the high velocities in these reaches, and may have to continue being maintained if this option turns into a long-term project.

Results indicate that this option will potentially re-establish South Slough as the dominant channel in the project area, but will also stress the levees along the middle reach of Dutchman Slough where the slough was excavated at the time of diking. These reaches already have levee maintenance issues under existing conditions, and the problem would just continue. In addition, circulation within Cullinan Ranch is poor and potential water quality problems may arise over time. The second phase of the Pond 3 restoration (breaching to Dutchman Slough) may require armoring of specific reaches of Cullinan Ranch levees near the Pond 3 breaches because of failure concerns.

Over time, South Slough will enlarge and probably convey more flow than immediately after construction, and thus relieve some of the pressure on the Dutchman Slough levees. An additional simulation assuming scour in South Slough was conducted to represent interim conditions as described in the next section(Case 7b).

Table 5.1-7A: Simulation Results For Case 7a

Water Levels

Location		H.W.	L.W.	Range	
		(ft, NGVD)		(ft)	% of Ex.
Dutchman Slough	P1	3.7	-2.5	6.2	98%
	P2	3.7	-1.8	5.5	87%
	P3	3.7	-1	4.7	75%
	P4	3.6	-0.2	3.8	60%
	P5	2.9	0.6	2.3	37%
	P6	2.9	0.7	2.2	35%
South Slough	P22	3.7	-2.5	6.2	98%
	P23	3.6	-2.3	5.9	94%
	P24	2.9	0.6	2.3	37%
	P7	2.9	0.7	2.2	35%
	P8	3.1	0.3	2.8	45%
G.V.	P10-P11	3.7	-1.8	5.5	87%
C.R.	P12-P21	2.9	0.7	2.2	---

Velocities and Tidal Prism

Location		Maximum Velocity		Diurnal Tidal Prism	
		(ft/s)	% of Ex.	(acre-ft)	% of Ex.
Dutchman Slough	V1 / E2	4.6	256%	2293	229%
	V2	3	214%		
	V3 / E3	3.7	264%	1825	235%
	V4 / E4	3.9	279%	2036	356%
	V5 / E5	2.8	350%	2087	485%
South Slough	V9 / E13	2.1	162%	1549	174%
	V8 / E11	2.1	233%	841	274%
	V7 / E10	2.1	350%	335	644%
	V6 / E6	1.8	225%	587	213%
	P8 / E8	2.3	209%	607	723%

CASE 7B :– FULL RESTORATION, LIMIT NUMBER OF BREACHES, FULLY INTEGRATED WITH POND 3 – INTERIM CONDITIONS

For this simulation, the response of South Slough to the opening of Pond 3 and Cullinan Ranch was taken into account. Based on post construction conditions (Case 7a results), and using empirical relationships between tidal prism and slough geometry (Williams, et al. 2002), a larger South Slough channel section was used for this option. Other features of this option are similar to Case 7a.

Simulation results, presented in Table 5.1-7B and Figures 5.1-17 and 5.1-18, show some recovery of the tidal range. Within Cullinan Ranch, the high water levels are about 0.6 to 0.7 feet below existing conditions, and low water levels do not go below +0.3 ft elevation. Guadalcanal Village is also affected, where the high tide elevation remains unchanged, but the low tide elevation rises by about 0.6 ft. These results indicate that the enlarged South Slough channel section is still not large enough to handle the increased tidal flow, and will continue eroding until it reaches a new equilibrium with the tidal prism. Velocities in the middle portion of Dutchman Slough (point V4) show some decrease, as more flow is conveyed through South Slough, but is still higher than existing conditions.

The required channel sectional areas for the tidal range described above (based on empirical relationships between tidal prism and channel geometry) are also presented in Table 5.1-7B. The numbers indicate that the channels are still too small to convey the increasing tidal prism, and will continue eroding. As sediment deposits within the restored areas, the tidal prism will reduce and eventually the channel size will equilibrate to the tidal prism of the system. However, additional restoration of Ranch property to the east (by constructing more breaches for water quality in the future), would change hydrodynamic conditions again and would affect the equilibrium of the system.

Table 5.1-7B: Simulation Results For Case 7b

Water Levels

Location		H.W.	L.W.	Range	
		(ft, NGVD)		(ft)	% of Ex.
Dutchman Slough	P1	3.7	-2.5	6.2	98%
	P2	3.7	-2	5.7	90%
	P3	3.7	-1.2	4.9	78%
	P4	3.5	-0.4	3.9	62%
	P5	3.1	0.2	2.9	46%
	P6	3.1	0.3	2.8	44%
South Slough	P22	3.7	-2.5	6.2	98%
	P23	3.6	-1.7	5.3	84%
	P24	3.1	0.3	2.8	44%
	P7	3.1	0.3	2.8	44%
	P8	3.2	0	3.2	52%
G.V.	P10-P11	3.7	-1.9	5.6	89%
C.R.	P12-P21	3.1	0.3	2.8	---

Velocities and Tidal Prism

Location		Maximum Velocity		Diurnal Tidal Prism		Equilibrium Cross Sectional Area	
		(ft/s)	% of Ex.	(acre-ft)	% of Ex.	(m2)	% of Ex.
Dutchman Slough	V1 / E2	4.5	250%	2300	230%	438	165%
	V2	2.8	200%	---	---	---	---
	V3 / E3	3.6	257%	1819	234%	376	172%
	V4 / E4	2.9	207%	2011	352%	401	191%
	V5 / E5	2.8	350%	1936	450%	391	226%
South Slough	V9 / E13	2.8	215%	2278	256%	435	153%
	V8 / E11	2.6	289%	1790	583%	372	262%
	V7 / E10	3.8	633%	1339	2575%	308	592%
	V6 / E6	1.4	175%	766	278%	214	141%
	P8 / E8	2.1	191%	580	690%	179	216%

5.1.8 Case 8 :– Full Restoration, Fully Integrated With Pond 3 Construction – Interim Conditions

The primary objectives of this option are to integrate the project completely with Pond 3, establish South Slough as the dominant channel, enhance circulation, and develop a functional channel network pattern within Cullinan Ranch over time.

Two breaches to Dutchman Slough, at locations where historic channels were observed on aerial photographs, and Pond 3 breaches to Dutchman Slough were added to the Case 7 model. The purpose of the 2 additional breaches is to increase circulation inside Cullinan Ranch, and to develop a channel network between the east and west breaches. Simulation results of water levels, current speeds and tidal prism are presented in Table 5.1-8 and Figures 5.1-19 and 5.1-20.

Simulated water levels show that damping is significantly reduced as compared to Case 7a. High water levels are similar to existing conditions, low water levels vary from -2.5 ft near the slough entrances to -0.3 ft inside Cullinan Ranch and near the confluence of Dutchman and South Sloughs.

Simulations indicate that at the mouth of Dutchman Slough, peak velocities will increase to about 4 times compared to existing conditions. The velocity in the middle portion of Dutchman Slough (between the entrance and the confluence with South Slough) decreases by about 15%. This suggests that the mouth of the slough will enlarge while its western portion will see deposition, which more closely resembles historical conditions when Dutchman Slough and South Slough were poorly connected. Velocities in South Slough near it confluence with Dutchman Slough will also increase, with the maximum increase being in the range of 5 to 6 times that of existing conditions.

The required channel sectional areas for the tidal range described above (based on empirical relationships between tidal prism and channel geometry) are also presented in Table 5.1-8. The relationships indicate that the mouth of Dutchman Slough should be about 2.4 times larger than existing conditions, and the middle portion should be about 25% smaller. If a bypass channel through Pond 3 (similar to that of Case 2a) were added to this alternative, peak velocities through Dutchman Slough would decrease and the potential erosion at Pritchard Marsh may be reduced. However, this would require coordination with the Pond 3 restoration project, which is further along in its planning process, and potential re-evaluation of the Pond 3 preferred alternative.

The empirical relationships and simulations also indicate that the mouth of South Slough should be about 60% larger than existing conditions (addition of Ponds 4 and 5 would increase this even more), and the portion between China and Dutchman Sloughs should be about 5 times the existing cross sectional area.

The findings above indicate that the mouths of both sloughs will scour over time. As the mouth becomes larger the damping within Cullinan Ranch will reduce and the tidal prism will increase, which in turn may cause the mouth to enlarge more. As sediment deposits within the restored areas, the tidal prism will reduce and eventually the channel size will equilibrate to the tidal prism of the system.

Table 5.1-8 Simulation Results For Case 8

Water Levels

Location		H.W.	L.W.	Range	
		(ft, NGVD)		(ft)	% of Ex.
Dutchman Slough	P1	3.7	-2.5	6.2	98%
	P2	3.7	-1	4.7	75%
	P3	3.7	-0.4	4.1	65%
	P4	3.7	-0.3	4	63%
	P5	3.7	-0.3	4	63%
	P6	3.7	-0.3	4	63%
South Slough	P22	3.7	-2.5	6.2	98%
	P23	3.7	-1.8	5.5	87%
	P24	3.7	-0.3	4	63%
	P7	3.7	-0.3	4	63%
	P8	3.7	-0.6	4.3	69%
G.V.	P10-P11	3.7	-1	4.7	75%
C.R.	P12-P21	3.7	-0.3	4	---

Velocities and Tidal Prism

Location		Maximum Velocity		Diurnal Tidal Prism		Equilibrium Cross Sectional Area	
		(ft/s)	% of Ex.	(acre-ft)	% of Ex.	(m2)	% of Ex.
Dutchman Slough	V1 / E2	7.4	411%	3956	395%	622	235%
	V2	3	214%	---	---	---	---
	V3 / E3	2.3	164%	1416	182%	319	146%
	V4 / E4	1.2	86%	507	89%	164	78%
	V5 / E5	1	125%	357	83%	131	76%
South Slough	V9 / E13	3	231%	2377	267%	447	157%
	V8 / E11	2.8	311%	1617	527%	348	245%
	V7 / E10	3.4	567%	970	1865%	250	481%
	V6 / E6	0.7	88%	258	93%	106	70%
	P8 / E8	1.9	173%	419	499%	145	175%

5.1.9 EXPECTED CHANNEL SCOUR

The likely channel scour following the breach opening for the restoration options is provided by empirical geomorphic relationships between tidal prism and the width, maximum depth and channel cross-section area for tidal slough channels in San Francisco Bay. These relationships are described in Coats, et al. (1995) in a study prepared for the Corps of Engineers Waterways Experiment Station. They have been recently updated and supplemented with new data from the lower Napa River and other sites around the Bay (Williams, et al. 2002).

Table 5.1-9 shows both the surveyed and required (per the relationships) dimensions for Dutchman Slough at V1, between the slough mouth and the opening to the Guadalcanal Village restoration site. Note that the depth, width and cross sectional area predicted by the empirical relationships are within 10% of the surveyed dimensions at the cross section near V1.

Table 5.1-9 Channel Geometry at V1 near Mouth of Dutchman Slough

	Diurnal Tidal Prism	X-Sec. Area below MHHW	Max. Depth below MHHW	Max. Width at MHHW	Depth of Scour
	Ac-ft	ft^2	ft	ft	ft
Surveyed Section - Existing	1002	2,852	15.7	360	--
Required Section - Existing	1002	2,799	15.1	312	--
Required Section - Case 8	3956	6,695	19.0	584	3.3

The table also shows the equilibrium dimensions of the channel with the increased tidal prism for Case 8 (Full restoration, fully integrated with Pond 3). The equilibrium width would be about 60% more than the existing channel width at MHHW, the channel would be deeper by about 3.3 ft, and the cross-sectional area would increase to approximately 2.3 times that for existing conditions. This indicates that natural channel widening may involve not just erosion of vegetated marsh, but also of levees, on one and/or both sides of the channel. Part of the Pritchard Marsh, and levees along Guadalcanal Village wetland and Pond 3 could see erosion.

The timing of the predicted channel adjustment is uncertain, depending on soil properties, particularly the shear strength of the soil. For typical San Francisco Bay Mud, erosion may start at a bed shear stress between 0.5 and 1.3 N/m^2 (Partheniades, 1965). The approximate timelines of cross sectional area evolution near the mouth of Dutchman Slough were estimated using different bed critical shear stresses, and results are presented in Figure 5.1-21. Results show that the channel cross sectional area evolution is very sensitive to the bed critical value of erosion. Using average tide condition, the estimated timelines of channel development near Dutchman Slough vary from 2 years to 20 years if the critical bed shear stresses vary from 0.6 N/m^2 to 1 N/m^2.

At Warm Springs Marsh in South San Francisco Bay, Coyote Slough increased in cross-sectional area by 57 percent in 9 years and by 98 percent within 13 years following a levee breach that increased the tidal prism to about 8 times that of existing conditions (Williams et al., 2002). For the Ranch + Pond 3 project (Case 8), the tidal prism would increase to about 4 times the existing condition. It seems reasonable to suppose that the predicted adjustments (to 2.3 times existing cross-sectional area) would occur over a decade or two.

Channel enlargement would probably begin with scouring of the bed, which would destabilize the channel side slopes. This in turn would accelerate bank failure (by slumping), both in the vegetated marsh that exists along the channel in some sections, and along the levees, which already are actively eroding in some spots.

The maximum channel dimensions predicted by the empirical geomorphic relationships, however, are not the ultimate dimensions. As sediment accumulates in Cullinan Ranch, the tidal prism will gradually decrease. The channel reaches scoured in the first few years after breaching will then begin to aggrade, losing width and depth, and forming a new vegetated marsh along the margins.

5.2 SEDIMENTATION

In order to estimate the rate of sediment accretion at Cullinan Ranch for the different cases (restoration options), we used a 1-dimensional sedimentation model (Ray Krone, 1987). The main variables in the model that determine the rate of marsh accretion are: 1) tidal input; 2) rate of sea level rise; 3) average sediment concentration; and 4) dry density of the bed material. Tidal input files were prepared from the hydrodynamic model simulations. Since the tides within a given pond for each scenario are about the same across the entire pond, we used one analysis point for each case.

For the rate of sea level rise we used 2.0 mm/yr, which is consistent with the median-level predictions of the Intergovernmental Panel on Climate Change. The recent historic rate for San Francisco Bay is about 1.8 mm/yr (Douglas, 1991).

Two sources of information were available for deriving the concentration of suspended sediment. The first is the study by Warner et al. (1999), which includes suspended sediment data from Dutchman Slough for the period of September 1997 to March 1998. Table 5.2-1 shows the summary statistics for the samples, which were taken by optical backscatterance sensors (OBS). The limitations of this data should be kept in mind. The authors of the study state that the instrument at Dutchman Slough was never calibrated *in situ*, and that the data should be used with caution. Second, the 1997-98 was a year of major floods, so data from fall to spring may be on the high side.

Table 5.2-1 Summary Statistics - Suspended Sediment In Dutchman Slough
(Warner et al., 1999)

Sample size	9660
No. of days	67
Mean, mg/l	92.5
Standard Deviation (SD), mg/l	63
-1 SD, mg/l	29.4
+1SD, mg/l	155.7
25th percentile, mg/l	40
50th percentile, mg/l	70
75 percentile, mg/l	147

The second source of data is 2 sediment cores taken at White Slough, on the east side of the Napa River. The average dry density of those cores, 420 kg/m^3, was used with the Krone model to find the sediment concentration that produced the observed rate of sediment accumulation. This was estimated to be 115 mg/l. This was possible because the timing of the levee failure at White Slough was known, and the old hayfield surface was readily identifiable. The dry density from the White Slough cores was used in this analysis, but it should be noted that it is low compared to the average used by Krone for marshes elsewhere in the Bay Area. The difference may result from the relatively young age of the White Slough sediments. Johnson et al. (1994) used the same procedure with a core at the mouth of Dutch Slough, and calculated an average concentration of 95 mg/l.

The above described sedimentation analysis is similar to the methods used to estimate the rate of sediment accumulation in the Napa salt ponds following re-introduction of tidal action (Philip Williams, 2002). The values used in that analysis were 125 mg/l for sediment concentrations (derived from a sediment budget analysis) and 400 kg/$m^3$for bed density. A subsequent section of the same report states that :

> *"(i)t is our opinion that suspended sediments are likely to be lower than those used in (our) habitat estimates."*

We agree with the above statement, and used a slightly lower suspended sediment concentration for our analysis. Figure 5.2-1 shows the predicted elevations for the cases analyzed, using a median concentration of 70 mg/l (based on Warner et al. 1999). The median is a better statistic than the mean, since the latter may be biased by a few extreme concentrations. The differences in the curves reflect the differences in tidal range and tidal muting of the various cases.

According to Siegel (1998), marsh vegetation in the Napa estuary can establish by seedlings on new mud flats once the elevation reaches about 1 ft above Mean Tide Level (MTL). MTL is the average of MHW and MLW. Since elevations of MHHW and MLLW were known from the simulation results, they were averaged for each case to estimate the elevation of MTL. Table 5.2-2 shows the estimated time required for sediment to be deposited to an elevation 1 ft. above MTL, for the cases analyzed.

Table 5.2-2 Restoration Timeline For Low Marsh Plain Colonization

Case	Estimated years to reach MTL + 1 ft
1	40
2	100+
3	85
4a, 4b	100+
5	40
6	55
7a	85
8	60

The tidal muting described in Section 5.1 acts in two ways to increase the time required for the marsh plain to reach one ft above MTL. First, the lower tidal range lowers the daily inflow of sediment available for deposition. Second, tidal muting increases the low water elevation more than it decreases the high water elevation, so that MTL is increased. This means that sediment must be deposited to a higher elevation before plants can become established.

Two limitations of the one-dimensional sediment deposition model on which Table 5.2-2 results are based must be kept in mind.

1. The model assumes that the tidal regime will not change, except in response to sea level rise. MTL was calculated once for each case, and not adjusted over time for changing hydrology or changes in channel morphology. As observed from the simulation results, the opening of Cullinan Ranch (and to a lesser extent Pond 3) will initiate scour in Dutchman Slough and South Slough, which will increase the tidal range in the project area. It will also result in a lowering of the MTL to near-existing conditions. Both these phenomenon would result in *reducing* the time required to attain marsh plain elevation from those shown on Table 5.2.2.
2. The model assumes that the supply of suspended sediment in incoming tides is not affected by the deposition of sediment in the marsh, or by the increased concentration available from channel erosion. In reality, there will not be a complete exchange of water with the Napa River on every tidal cycle; some water that loses its sediment load to the bed on one cycle will remain in the marsh or be returned on the next tidal cycle. This would result in *increasing* the time required to attain marsh plain elevation from those shown on Table 5.2.2.

PWA (2002) estimated the tidal excursion length from restored Napa salt ponds to be 1.2 to 1.6 times the length of Mare Island Strait, which suggests that there would be some replenishment of sediment from San Pablo Bay and Carquinez Strait on a daily basis. Because of uncertainties about the sediment concentration in the restored marsh, the results should be considered relative rather than absolute estimates of the time required before salt marsh vegetation can begin to develop in the restored Cullinan Ranch.

Case 1 assumes no Pond 3 or Cullinan Ranch opening, and Case 5 assumes that Pond 3 is opened, but not Cullinan. The sediment deposition curves, essentially the same for both cases, show the rate that may be expected in a backwater along Dutchman Slough, if deposition began at the average elevation of the Ranch. Because there is little or no tidal damping in these “No Action Alternatives”, they have the highest rates of sediment accumulation.

In Cases 2, 3, 4a, 4b, 6, 7a and 7b, the damping of the tides prolongs the time required to develop a vegetated marsh. In Cases 4a, 4b and 2, the time would be well in excess of 100 years. Because of uncertainties about sea level rise and sediment supply, it is not reasonable to extend the estimates much beyond that time frame.

Case 8, which is the full restoration option with Pond fully integrated, would provide a rate of sediment deposition very close to that of Cases 1 and 5. This is because the tide cycle assumes that a shoal at the confluence of Dutchman and South Sloughs is scoured relatively quickly, removing a constriction that otherwise would dampen the tides.

5.3 EXPECTED EVOLUTION OF HABITAT IN THE RESTORED AREAS

The marsh sedimentation model discussed above is a 1-dimensional model; it can tell us an average rate of sediment deposition at a point, but cannot show the distribution of sediment deposition or marsh development in plan view. From previous studies and experience with marsh development, however, it is possible to infer how the new marsh at Cullinan Ranch will evolve.

Johnson et al. (1994) applied the 2-dimensional RMA-2 tidal hydrodynamic model at Cullinan Ranch, and developed maps showing elevation contours over a 5-yr period following the opening of the Ranch to tidal action. Their "Scenario 3" involved opening of 3 breaches 500 ft wide in the levees between the Ranch, Dutchman Slough and South Slough. Our Case 8 includes 4 breaches each 300 ft wide. Their results show that sediment shoals develop first near the breach openings, and along the north side of the marsh. This is to be expected, since the sediment will drop out of the water where velocities first decrease.

The sinuous pattern of channels in tidal marshes does not result from active channel meandering; rather the pattern develops as meanders on an unvegetated mudflat at low slope. As sediment accumulates, the marsh plain gains in elevation and vegetation, and the channels continue to incise into the developing marsh plain.

Channels in Cullinan Ranch will begin forming just inside the breaches, as deep scour holes, with shoals on each side. The channels will most likely turn slightly toward the right, since the incoming tidal jets will be turned due to the Coriolis effect. As sediment accumulates, smaller sinuous channels will form to drain the developing marsh plain. We expect that for the full restoration alternative (Case 8) a large channel will become established within Cullinan Ranch, which will connect to the lower portion of Dutchman near the first proposed breach.

The emerging shoals will first be colonized by cordgrass (*Spartina foliosa*) and bulrush (*Scirpus sp.*). The relative dominance of these colonizers will be influenced by salinity, and may shift over time depending on outflow from the Napa River and Delta, and possibly the release of hypersaline water from near-by salt ponds that are being restored. Around the upper edges of the marsh, where salt concentrations will build up in the soil and tidal inundation is less frequent, pickleweed, (*Salicornia virginica*), salt grass (*Distichlis spicata*), alkalai heath (*Frankenia salina*), Jaumea (*Jaumea carnosa*) and brass buttons (*Cotula coronopifolia*) will become established.

The cattails and other brackish marsh plants presently occupying the site will be killed shortly after the introduction of tide water, either by salinity or by prolonged inundation. The biomass of dead plant material will provide a plentiful substrate for invertebrates and rich supply of fine particulate organic matter to the estuary. It may also temporarily exert a powerful demand on dissolved oxygen (DO) in the water.

Over the long run, the trajectory of habitat development in the marsh will be controlled not only by exogenous variables (sea level rise, sediment supply, and salinity), but also by a complex set of positive and negative feedbacks. Following the initial breaching of the levees, the lower portion of Dutchman Slough near the mouth, and (to a lesser extent) South Slough will deepen and widen in response to the increased tidal prism. This will increase both the tidal range on the site, and temporarily, the supply of sediment. Within a few years, new equilibrium channel dimensions will become established, possibly constrained by levees along the channels. As sediment continues to accumulate in the marsh, however, both the marsh tidal prism and the marsh's demand for sediment will eventually decrease. At this point, the outer channel will begin to aggrade, and a new marsh will form along the channel margins. Our estimate of the time required to reach this point is about 60 years, but the timing could be strongly influenced by changes in the sediment supply, the salinity regime, and the rate of sea level rise.

6 SUMMARY OF FINDINGS AND RECOMMENDATIONS

6.1 SUMMARY OF FINDINGS

1. Dutchman and South Sloughs, between Napa River and the westerly limit of the Cullinan Ranch property, are well connected to tidal sources and do not exhibit significant variations in tidal statistics. Napa River to the east and Sonoma Creek to the west provide adequate hydrologic connectivity to the Bay. The convergence zone, where tides from both sources meet, is close to the westerly limit of the property. The phase lag between Napa River and the westerly limit is about 20 minutes (Napa River is earlier).
2. The existing tidal prism at the mouth of Dutchman Slough is about 1000 acre-feet, and the prism at the mouth of South Slough is about 900 acre-feet. This is expected to change significantly for almost all of the restoration options considered, because of the low elevations within Cullinan Ranch and the expected full tidal range within Pond 3.
3. Elevations within the Ranch are low enough that tidal damping occurs for all restoration scenarios. This lower tidal range will persist over time until the sloughs scour out to equilibrium conditions. This damping occurs primarily within the Ranch and near the confluence of South and Dutchman Sloughs.
4. Scour effects near the mouth of Dutchman Slough are mostly because of the Ranch restoration, although Pond 3 contributes to some increase in velocity (see Case 5).
5. Scour effects near the mouth of South Slough are mostly because of the Napa Ponds project, with an increasing contribution from the Ranch project as South Slough scours over time (see Cases 2 and 3).
6. South Slough, between Dutchman and China Sloughs, has seen a significant amount of sediment deposition since diking, and is a hydraulic constraint to almost all Ranch restoration options (except Case 4a – Partial restoration along east side). This will temporarily result in significant damping of tides within the Ranch and high velocities in South Slough, until the channel enlarges by bank erosion and bed lowering.
7. Hydraulically limiting the increase in tidal prism by reducing the size and/or number of breaches (Cases 2, 3, 7) or by restoring only portions of the Ranch site (Cases 4a, 4b, 6), will require long-term levee maintenance and management of habitat within unrestored portions of the site. The risk of levee failure will be higher than for existing conditions, because all restoration options result in increases in velocities along different portions of Dutchman Slough.
8. Restoration of Cullinan Ranch should be fully integrated with Pond 3’s Phase 1 and Phase 2 design features, because Dutchman Slough by itself is not adequate to convey flow from/to the Ranch without affecting local hydraulics significantly. Pond 3’s proximity to Napa River will minimize impacts of the Ranch restoration on Pond 3. Historically, the system functioned as a single marsh unit with South Slough being the largest tidal channel. Hydrologic connectivity with Pond 3 will benefit the system as a whole, and allow a dendritic pattern to develop within the Ranch as well as Pond 3.

6.2 DISCUSSION AND RECOMMENDATIONS

Study results show that all Full Restoration options will affect the existing local hydrology, because the sloughs are inadequate to convey the larger tidal flows after restoration. However, integrating the Pond 3 project with the Ranch project and constructing breaches in the lower reaches of Dutchman Slough (near the mouth, as described for the Case 8 option) reduces damping in the Ranch, and allows for better circulation and predictability of channel creation.

Erosion along the banks of both sloughs will mostly likely occur for all the Full Restoration options. Along Dutchman Slough this may present problems in the lower reach near the mouth, where other properties may be affected including Guadalcanal Village, Pritchard Marsh and the Pond 3 levees. However, if Pond 3 is restored, erosion of its levees will not be a concern. Some of the low marsh habitat within Guadalcanal, along with sections of the old perimeter levee, may be eroded. There is a high probability that portions of Pritchard Marsh, because of its proximity to both restoration projects and the increase in velocities in Dutchman Slough, will erode along the slough and along Napa River. This may need to be mitigated by installing protective measures such as sheet piles or other forms of bank protection along the affected areas.

For South Slough, between the mouth and the confluence of South and Dutchman Slough, it is expected that the channel will enlarge by scouring and the fringe marshes along the banks will be incised. The empirical analysis (tidal prism versus channel width relationships) indicates that up to 20% of the fringe marsh in this area may erode over time. The damping within the Ranch and near the confluence of Dutchman and South Sloughs will be temporary until the shoal in this area is scoured out. Dredging the shoal (deepening the channel) at the time of construction of the Ranch project should be considered to mitigate the damping effects.

Table 6.1-1. Summary of Water Levels - All Options

Location	Existing Conditions[1] (ft, NGVD datum)			Post-Ranch Restoration (Pre-Pond 3 Construction) Initial Conditions (% of existing range)				Post-Ranch Restoration (Post-Pond 3 Construction) Initial Conditions (% of existing range)			Post-Ranch Restoration (Post-Pond 3 Construction) Interim Conditions (% of existing range)	
	High	Low	Range	Full Site (5 Breaches)[2]	Full Site (2 Breaches)[3]	East Only[4a]	West Only[4b]	No Action[5]	West Only[6]	Full Site (2 Breaches)[7a]	Full Site (2 Breaches)[7b]	Full Site (4 Breaches)[8]
Dutchman Slough												
Near Napa River	3.8	-2.5	6.3	70%	90%	100%	100%	100%	100%	90%	90%	70%
Midway To So Slough	3.8	-2.5	6.3	50%	70%	100%	90%	100%	90%	70%	80%	70%
Near So. Slough	3.8	-2.5	6.3	50%	30%	100%	90%	100%	80%	40%	50%	60%
South Slough												
Near Napa River	3.8	-2.5	6.3	100%	100%	100%	100%	100%	100%	100%	100%	100%
Near Dutchman Slough	3.8	-2.5	6.3	50%	30%	100%	90%	100%	80%	40%	40%	60%
West End	3.8	-2.4	6.2	60%	40%	100%	90%	100%	80%	50%	50%	70%
Guadalcanal Village	3.8	-2.5	6.3	70%	90%	100%	100%	100%	100%	90%	90%	70%

SIMULATION CASE & DESCRIPTION

1 No Action (Existing Conditions)

Ranch Restoration Without Pond 3 Restoration

2 Full Restoration – Vary breach size to limit tidal prism

3 Full Restoration – Limit number of breaches to limit increase in tidal prism

4a Partial Restoration – Restore 300 acres along east side of site only

4b Partial Restoration – Restore 300 acres along west side of site only

Ranch Restoration Integrated With Pond 3 Restoration

5 No Action - Pond 3 restored, but no breaches to D.S.

6 Partial Restoration - Pond 3 restored, but no breaches to D.S., Restore 300 acres along west side of site only

7a Full Restoration, Limit number of breaches to limit increase in tidal prism, Fully integrated with Pond 3, Initial Conditions

7b Full Restoration, Limit number of breaches to limit increase in tidal prism, Fully integrated with Pond 3, Interim Conditions

8 Full Restoration, Fully integrated with Pond 3, Interim Conditions

Table 6.1-2. Summary Of Peak Velocities - All Options

Location	Existing Conditions[1]	Post-Ranch Restoration (Pre-Pond 3 Construction)				Post-Ranch Restoration (Post-Pond 3 Construction)				
		Initial Conditions (% of existing range)				Initial Conditions (% of existing range)			Interim Conditions (% of existing range)	
	(ft/s)	Full Site (5 Breaches)[2]	Full Site (2 Breaches)[3]	East Only[4a]	West Only[4b]	No Action[5]	West Only[6]	Full Site (2 Breaches)[7a]	Full Site (2 Breaches)[7b]	Full Site (4 Breaches)[8]
Dutchman Slough										
Near Napa River	1.8	360%	240%	190%	150%	130%	170%	260%	250%	400%
Midway To So Slough	1.4	160%	250%	90%	170%	120%	190%	260%	260%	160%
Near So. Slough	0.8	50%	350%	90%	230%	150%	250%	350%	350%	130%
South Slough										
Near Napa River	1.3	120%	110%	90%	100%	160%	170%	160%	220%	210%
Near Dutchman Slough 1	0.6	420%	400%	270%	300%	120%	250%	350%	630%	570%
Near Dutchman Slough 2	0.8	40%	130%	90%	300%	100%	300%	230%	180%	90%
West End	1.1	190%	200%	80%	150%	100%	150%	210%	190%	170%

SIMULATION CASE & DESCRIPTION

[1] No Action (Existing Conditions)

Ranch Restoration Without Pond 3 Restoration

[2] Full Restoration – Vary breach size to limit tidal prism
[3] Full Restoration – Limit number of breaches to limit increase in tidal prism
[4a] Partial Restoration – Restore 300 acres along east side of site only
[4b] Partial Restoration – Restore 300 acres along west side of site only

Ranch Restoration Integrated With Pond 3 Restoration

[5] No Action - Pond 3 restored, but no breaches to D.S.
[6] Partial Restoration - Pond 3 restored, but no breaches to D.S., Restore 300 acres along west side of site only
[7a] Full Restoration, Limit number of breaches to limit increase in tidal prism, Fully integrated with Pond 3, Initial Conditions
[7b] Full Restoration, Limit number of breaches to limit increase in tidal prism, Fully integrated with Pond 3, Interim Conditions

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